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A. Levy and G. Hickey

January 1985

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**EROSION OF CORROSION-RESISTANT SURFACE
TREATMENTS ON ALLOY STEELS**

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ABSTRACT

Protective coatings of both diffused and sprayed on types are being used to protect chemical process plant and boiler combustor surfaces from elevated temperature corrosion. An investigation was conducted to determine the small, solid particle erosion behavior of such coatings at room and elevated temperatures. It was determined that no single coating performed in a superior manner to the others and that hardness was not a factor in establishing erosion resistance. The erosion rates decreased from 20°C to 500°C. All of the coatings reached steady state erosion rates after 50-150g of erodent particles had impacted their surfaces.

INTRODUCTION

Protective coatings are used on components in chemical process plants and boilers to protect the surfaces of structural steel alloys against corrosion and wear. These coatings are applied to steel surfaces using primarily diffusion or spraying processes. Representative coatings were selected and applied to carbon and austenitic stainless steel specimens to determine the nature of their solid particle erosion behavior at both room and elevated temperatures. The diffused coatings were applied by chromizing, aluminizing, and carburizing. The sprayed coatings were applied by flame and plasma spraying.

The firms that applied the coatings were selected because of their demonstrated expertise and the industrial success of their coatings on large numbers of components that are in service. Two aluminizing sources were selected, one that applies coatings to large chemical

process plants components and the other that has had extensive experience in coating aircraft engine parts.

The test conditions were selected to be representative of portions of the operating environments of entrained coal gasifiers and pulverized coal boilers and fluidized bed combustors. The room temperature tests were used to obtain incremental erosion rates curves that provide insight into the mechanisms of erosion which are occurring.

The objective of the investigation was to determine the mechanism of erosion of the different types of protective surface treatments and to relate them to their resulting erosion rates. The morphologies of the eroded surfaces and their cross sections are keys to establishing the mechanisms of erosion. The ranking of the various coatings for erosion resistance was not considered, per se, in analyzing the test results. In order to rank coatings performance in a meaningful manner to the component designer, test conditions that are closer to the operating environment in a gasifier or combustor than those used would have had to be utilized.

EXPERIMENTAL CONDITIONS

Flat, rectangular specimens, 3cm x 2cm x 1/2 cm. of the different diffusion and surface coatings were prepared by the manufacturers and shipped to LBL for erosion testing. Table 1 lists the seven materials tested and their as-applied thicknesses. Table 2 lists the compositions of the METCO sprayed coatings and their densities and hardnesses.

The program was conducted in two parts; room temperature incremental erosion and elevated temperature, single, 200g load

erosion in an inert gas environment at 500°C and 750°C.

The room temperature erosion tests were conducted using an air blast tester which is described in detail in Reference 1. The specimens were eroded incrementally in small gram increments with a total of 200g of 240 μ m SiC particles. The particles were entrained in an air stream at a particle velocity of 30m/s, as determined by the rotating disc method, and directed toward the specimens through a 0.47cm I.D. nozzle at either a $\alpha=30^\circ$ or 90° impingement angle. Angular SiC particles were used to eliminate the variables of particle hardness differences with the hard coatings and the possibility of weaker erodent particles shattering when they impacted the target surface.

The specimens were eroded until a steady state erosion rate was reached which occurs when each succeeding increment of particles causes the same amount of weight loss as the preceeding increment. The specimens were cleaned after each test increment and weighed on an analytical balance with a precision of 0.1 mg. It was observed for all specimens that steady state erosion was reached before 200g of erodent had impacted the surface.

Elevated temperature erosion rate tests were carried out using the LBL elevated temperature erosion tester shown in Figure 1 at 500°C and 750°C. The specimens and carrier gas temperatures were controlled to within $\pm 10^\circ\text{C}$ by a thermocouple and controller. This piece of equipment operates in the same manner as the room temperature erosion tester. A single, filament wound furnace encapsulates the gas-particle mixing chamber where the particles are preheated, the nozzle and specimen holder where a thermocouple is located, and a several foot long

coil heat exchanger placed around the nozzle that heats the undried nitrogen carrier gas prior to its entering the mixing chamber.

The elevated temperature erosion tests were conducted in one cycle using 200g of particles and a 10g/min particle loading. The particles were entrained in the nitrogen carrier gas to minimize oxidation of the specimens during the experiment. The pressure drop across the nozzle was set using a computer program that takes elevated temperatures into account.² The particles impinge upon the surface at a velocity of 30m/s at either $\alpha=30^\circ$ or 90° . After completion of the experiment the specimens were cooled in a cold nitrogen stream. Some leakage of air occurred during transfer to the nitrogen cooling stream which resulted in some oxidation on the specimens at the 750°C test temperature. This was kept at a minimum for all of the chromium containing surfaces and only adversely affected the results of the carburized 1005 steel at 750°C.

RESULTS

Room Temperature Erosion

Figure 2 presents the room temperature steady state erosion rates for the seven materials being investigated. The erosion rates have been normalized for the different densities of the materials and are presented as volume of material removed per gram of erodent. The materials are presented generally in terms of decreasing hardness from left to right, with the steady state rate of 1018 steel given as a reference.

From Figure 2 it can be seen that there is no direct hardness correlation with erosion behavior for these different materials, as has

been observed previously.³ For example the carburized 1005 (350VHN) has a lower erosion rate than the much harder chromized 1060 (975VHN). The three hardest materials, the chromized and the two aluminized diffusion treated steels all had greater erosion rates at $\alpha=90^\circ$ than at $\alpha=30^\circ$. Carburized 1005 and the three METCO coating showed the opposite behavior, having greater erosion rates at $\alpha=30^\circ$ than at 90° .

Figure 3 shows the room temperature incremental erosion rate curves for the four diffusion type surface treatments at $\alpha=90^\circ$ impingement angle. The curves for the $\alpha=30^\circ$ were similar. In general the incremental curves follow the same forms that have been seen in ductile steels,⁴ having a low initial rate, reaching a peak after 30 to 50g of impacting particles and then reaching a steady state erosion rate that is considerably lower than the peak rate. Several of the materials had no measureable erosion after the first increment of eroding particles. These data points represent cases where the initial weight loss was less than 0.1 mg per increment of particle. All of the surface diffused coatings had steady state erosion rates that were similar, particularly at $\alpha=30^\circ$. Their behavior differed primarily in the erosion initiation stages where the peak erosion occurred.

One exception to the general shape of the erosion curve in Figure 3 was the aluminized 304SS. As seen in Figure 3 for chromized 1060, the ratio between the peak and the steady state erosion rates is much higher than for the other materials. The three materials with well defined peaks all had them occur at the same amount of impacting particles. The amount of erodent for chromized 1060 to reach steady state erosion is much greater than that for the other materials. 100

to 150g of erodent was needed for chromized 1060 to reach steady state erosion whereas for all of the other materials only 50g of erodent was needed under the same conditions.

Figure 4 shows the room temperature incremental erosion rate curves at $\alpha=90^\circ$ for three Metco coatings. The curves for the $\alpha=30^\circ$ tests were similar. The Metco coatings are fine grained (45-106 μ m), thermal sprayed powders whose compositions and physical characteristics are given in Table 2. The primary difference between the Metco coatings and the surface diffusion treated steels is their higher degree of surface texture as the result of the splat size and the presence of some porosity (less than 1%) from the spraying operation.

As a result of the surface texture, all of the coatings had high initial erosion rates at $\alpha=90^\circ$ and 30° which decreased to lower steady state rates.⁵ The high initial erosion rates occurred because the coatings' surface protrusions have little mechanical support from the bulk of the material below them and are vulnerable to removal by the impacting particles.

It should be noted that in Figures 2 and 4 the macrohardnesses of the Metco coatings and their microhardness equivalents are given. The macrohardness was measured because the surface texture did not lend itself to giving an accurate and reproducible measurement of the microhardness using a diamond point indenter.

Elevated Temperature Erosion

Figure 5 is a bar chart of the steady state erosion rate of the seven coatings at 500°C. The most striking change that occurred is that the erosion rates decreased by almost one half at 500°C from the

20°C rates. The decrease in erosion rates at moderately elevated temperatures has been seen in ductile metals.⁶ The erosion of the two hardest materials measured at room temperature, chromized 1060 and TCC Aluminized 304SS, had very little angular dependence at 500°C. The other materials showed some angular dependence, having lower erosion rates at $\alpha=30^\circ$ than at $\alpha=90^\circ$. For the Metco coatings and the least hard of the surface diffusion coatings, carburized 1005, their angular dependence is opposite to their erosion behavior at room temperature.

Figure 6 is a bar chart of the steady state erosion rate of the coatings at 750°C. This temperature was chosen as the highest test temperature because it is just below the maximum recommended useful operating temperature for each material where they still maintain their corrosion resistance. Also this temperature is at the limit of the test equipment used to prevent oxidation during the transfer of the specimens from the experimental test chamber to the inert gas cooling stream. Some oxidation did occur during transfer at this temperature but it appeared to be at a low enough level to not affect the test results for all the materials except the carburized 1005. For this reason results for carburized 1005 have been omitted.

In comparing Figures 5 and 6, there are distinct changes. The general trend for the diffused coatings was for the $\alpha=30^\circ$ rates to stay the same or increase somewhat while the $\alpha=90^\circ$ rates underwent significant increases, except for the TCC aluminized steel. The Metco coatings had lower erosion rates at $\alpha=90^\circ$ than at $\alpha=30^\circ$ at 750°C. This is the same behavior they showed at room temperature but the opposite of that which occurred at 500°C. This is the result of the slightly

higher erosion rates at $\alpha=30^\circ$ from 500°C to 750°C and significant decreases in the $\alpha=90^\circ$ rates at the higher temperature. The large increase in rate from 500°C to 750°C at $\alpha=90^\circ$ but minor increase in rate at $\alpha=30^\circ$ also occurred in the chromized 1060. The reasons for these changes are not known at this time. The Metco coatings performed better at 750°C compared to the surface diffusion coatings and not as well at 500°C .

The effect of the test temperature on the steady state erosion rates of the diffused coatings are shown in Figures 7 and 8. The curves for the METCO coatings were similar. The decrease in erosion rates at 500°C from the room temperature values can be readily seen. The 750°C rates at $\alpha=30^\circ$ stayed near constant or increased somewhat compared to the 500°C rates. All of the diffusion coatings had erosion rates at $\alpha=30^\circ$ that fell within a reasonably narrow band, Figure 7, compared to their behavior at $\alpha=90^\circ$ shown in Figure 8. At $\alpha=90^\circ$, the rates of the diffusion coatings had a more distinct minimum at 500°C and a much greater spread in rates at the lowest and highest test temperatures. The carburized 1005 steel was an exception. The reason for the observed relationships is not known at this time, but probably relates to changes in the mechanical properties and/or microstructures of the coatings. The reasons for the behavior of the coatings will be studied in future work.

Metallographic Analysis

A scanning electron microscope (SEM) was used to observe the surface of the eroded area on each of the specimens. An optical

metallograph was used to observe the cross sections. The surface textures of the four surface diffusion treated steels were all similar; so only the surface photos of the chromized 1060 are shown. Figures 9 and 10 show the eroded surfaces of the chromized 1060 steel at $\alpha=30^\circ$ and $\alpha=90^\circ$ at each of the three test temperatures. As mentioned earlier, some oxidation occurs at 750°C . There was consistently more oxidation at the $\alpha=90^\circ$ than at $\alpha=30^\circ$ for all seven materials at 750°C . No oxidation was observed at 500°C .

The surface of the chromized 1060 steel at $\alpha=30^\circ$ in Figure 9 shows a general pattern as the test temperature was increased. At 20°C , the basically brittle nature of the hard material can be observed. The surfaces of the particle impact areas are all smooth with no visible striations in them. This indicates a brittle, cleavage type of failure. A few cracks can also be seen. At 500°C the flat areas generally have striations in them, indicating that the surfaces are being plastically deformed. The occurrence of striations increases at 750°C . The striations are imprints of the irregular impacting surfaces of the silicon carbide particles.⁷

The same pattern can be seen to a lesser degree in chromized 1060 at $\alpha=90^\circ$ in Figure 10. As the material temperature is increased from 20°C to 500°C some evidence of striations, indicative of plastic flow, occurs. The presence of striations is obscured at 750°C due to oxidation. However, another sign of elevated temperature plastic flow, long, narrow gouges occurs at the highest test temperature.

All of the Metco thermal spray coatings also had a similar, surface appearance; so only the surfaces of Metco 15E will be presented

and discussed. In each photomicrograph the area shown is in the center of the eroded area. Figures 11 and 12 show the eroded surfaces of Metco 15E at $\alpha=30^\circ$ and 90° for the three test temperatures. No striations occur on the surfaces of the specimens tested at 20° and 500°C . The size of the flat areas are greater on the 20°C test specimens compared to the 500°C test specimens. Some striations occur on the 750°C test specimen at $\alpha=30^\circ$ but not at $\alpha=90^\circ$. Less evidence of oxidation occurs on the Metco 15E specimens at 750°C than occurred on the diffusion coatings. There is not a significant difference in the surface morphology between the $\alpha=30^\circ$ and 90° test specimens.

The cross sections of the coatings indicated that none of the six coatings tested had completely eroded off. In the cases of the diffusion coatings where the coating system consisted of more than one distinct layer, the outer, diffusion element rich layer was eroded off the carburized 1060 and the Alon aluminized 304SS. It was only partially eroded off the TCC aluminized 304SS. Figure 13 is representative of the diffused coatings where the outer layer, which contains approximately 50% aluminum, had completely eroded off.

The flame sprayed METCO coatings are represented by the cross sections of METCO 444 coating shown in Figure 14. It can be seen that the rough, as sprayed coating surface has been smoothed by the erosion action.⁵ The morphology and phase distribution of the coating did not appear to be modified by the erosion action. The amount of coating that was eroded off in the room temperature test can be seen by comparing the coating thicknesses in the before and after micrographs.

A cross section of the Metco 15E coating eroded surface is shown in Figure 15. It can be seen that significant cracking of the coating had occurred. The cross shaped cracks were typical of those found in all three of the Metco coatings.

DISCUSSION

Performance Comparisons

The comparative erosion rates of the various materials differed at the three test temperatures. Generally the diffused coatings had lower erosion rates than the sprayed coatings. However, there were exceptions of individual coatings at specific impingement angles and temperatures. There was no "most" erosion resistant coating over the whole test spectrum. Rather, the test data indicated trends of behavior, many of which will be discussed subsequently.

There was no hardness correlation among the coatings tested. The >900 VHN diffused coatings tested at 20°C generally eroded less than most of the softer materials. However, the carburized 1005 steel with a hardness of 350 VHN eroded less than they did at 20°C. At $\alpha=90^\circ$ the softest material, 1018 steel had a lower erosion rate at 20°C than all but the carburized 1005 steel. The lack of correlation with hardness is due to the effect that the ductility of the softer materials has on distributing the force of the impacting particles by plastic deformation which reduces the erosive potential of the particles. This effect has been observed before.^{7,8}

A particularly interesting comparison is the erosion behavior of the two aluminized 304SS diffusion coatings. The Alon coating was applied using a process that is suitable for the treatment of very

large components for the chemical processing industry. Supposedly, the control of the diffusion process for this coating is less precise than that of TCC coating which is generally applied to much smaller parts such as turbine engine components.

At 20°C both coatings performed exactly the same at both impingement angles, indicating that, from an erosion resistance standpoint, they were equal. At 500°C, their performance was the same at $\alpha=30^\circ$ but at $\alpha=90^\circ$ the TCC coating performed somewhat better than the Alon coating. At 750°C, the TCC coating had a significantly lower erosion rate than the Alon Coating. The reason for the progressive difference in magnitude of erosion rate with increasing test temperature relates to the morphology and composition of the surface layers, which will be discussed in a subsequent paper.

Ductile and Brittle Material Behavior

In the literature⁹ "ductile" materials are reported to have a higher erosion rate at $\alpha=30^\circ$ than at $\alpha=90^\circ$ with "brittle" materials behaving in an opposite manner. The types of surfaces eroded in this investigation had mixed credentials with both brittle and ductile constituents occurring in the surface layers. Comparing the bar graphs shows how mixed the performance of the different coatings were and how the mix changed with test temperature. At 20°C the diffused coatings behaved as brittle materials, except for the carburized 1005 steel, having greater erosion rates at $\alpha=90^\circ$ than at $\alpha=30^\circ$. The Metco coatings behaved as ductile materials with their higher erosion rates occurring at $\alpha=30^\circ$.

At 500°C test temperature, the trend reversed or became mixed for

the diffused coatings and for the Metco coatings. For some of the coatings there was no significant difference in erosion rates as a function of impingement angle. At 750°C, the trend reversed again, with some exceptions, for both the diffused coatings and the Metco coatings. Thus, the generally accepted rule that ductile materials erode more at $\alpha=30^\circ$ and brittle materials more at $\alpha=90^\circ$ was compromised in this investigation.

Another observation of the difference between the erosion behavior of ductile and brittle materials made by this author⁹ is that ductile materials have an increasing incremental erosion rate to an early peak erosion rate after which the rate decreases to a much lower, steady state erosion rate. Brittle materials, on the other hand, start their incremental erosion rate curves at a high rate at the first measureable amount of erosion and, subsequently, the rate decreases to a much lower steady state rate. This rule was also compromised in the present investigation. Figure 3, which plots the incremental erosion rate curves at 20°C test temperature for the diffused coatings shows a typical ductile material type of erosion rate, except for the Alon aluminized 304SS. This conflicts with the impingement angle effect for the same coatings tested at 20°C which indicated that the diffused coatings behaved like brittle materials because they eroded more at $\alpha=90^\circ$ than at $\alpha=30^\circ$.

The Metco coatings, whose incremental erosion rates are plotted in Figure 4, behaved like brittle materials because the first measureable erosion occurred at the highest incremental erosion rate. This conflicts with their 20°C test temperatures impingement angle rates,

which indicated a ductile material behavior because they eroded more at $\alpha=30^\circ$ than at $\alpha=90^\circ$.

Thus the generally accepted modes of ductile and brittle material behavior in erosion do not apply for these coatings which contain both ductile and brittle constituents in their surface layers. The reason that the Metco coatings started off at their highest incremental erosion rates is due to the fact that the as-sprayed surfaces had protrusions on them which were particularly vulnerable to being knocked off by the eroding particles. The reasons for all of the other conflicting trends and reversals with test temperature are not known at this time and will be the subject of future work.

Incremental Erosion Rate Curves

The amount of impacting erodent particles required to reach steady state erosion where each increment of eroding particles removes the same amount of material as the preceding increment has been related to the strain hardening coefficient in ductile materials.⁴ It is an important measurement as it indicates the length of time required to obtain a reliable erosion rate in a test. It can be seen in Figures 3 and 4 that this occurs at about 50g of erodent for all but the chromized 1060 steel, which took over 100g of particles to reach steady state erosion. Whether this is due to the fact that the chromized steel surface has a lower strain hardening coefficient than the other materials tested is not known. Brittle materials have been observed to reach incremental steady state erosion when a fully developed crack network has formed on the eroding surface and chipping out of similar size pieces of target material occurs. It appears that testing with

200g of particles would be sufficient for all of the materials to reach steady state erosion conditions.

The heights of the initial peaks of the incremental erosion rate curves for the diffused coatings in Figure 3 do not relate to their steady state erosion rates. The same lack of correlation applied to the Metco coatings curves in Figure 4. The steady state rates are remarkably close for all of the materials tested and are reasonably constant as indicated by the straight lines.

Elevated Temperature Effects on Erosion

The reduction in erosion rate at the intermediate test temperature of 500°C compared to the rates at 20°C and 750°C shown in Figures 7 and 8 has been observed for several ductile metals.⁸ It is thought to be due to an increase in the ductility of the eroding material without a commensurate significant reduction in its strength. As is the case with other behavior comparisons in this report, the trend of the 500°C data being the lowest is not absolute. In some cases the rates continue to fall to lower levels at 750°C. The trend for the minimum rate to occur at 500°C appears to be more pronounced at $\alpha=90^\circ$ than at $\alpha=30^\circ$. The reason for this is not known at this time.

The changes in the relative ranking of the erosion resistance of the various coatings tested as a function of test temperature at each of the impingement angles is a bit of a jumble. More work will be required to understand the ranking changes. One interesting observation is that the $\alpha=30^\circ$ erosion rates at 500°C and 750°C for the Metco coatings remained relatively constant while the $\alpha=90^\circ$ erosion rates decreased markedly at 750°C compared to their values at 500°C.

The reductions were sufficient to change the ranking of the impingement angle relationship. At 500°C more erosion occurred at $\alpha=90^\circ$ than at $\alpha=30^\circ$ while at 750°C. The reductions were sufficient to change the ranking of the impingement angle relationship. At 500°C more erosion occurred at $\alpha=90^\circ$ than at $\alpha=30^\circ$ while at 750°C the lower $\alpha=90^\circ$ rates were less than the more constant $\alpha=30^\circ$ rates.

The amount of corrosion which occurred on the coated surfaces that did oxidize at 750°C was greater for the specimens tested at $\alpha=90^\circ$ than for those tested at $\alpha=30^\circ$. This effect can be attributed to the height above the general eroding surface of the thin platelets of material which were formed at each impingement angle. The platelets extruded at $\alpha=90^\circ$ were higher than those formed at $\alpha=30^\circ$ and, therefore, were more subject to corrosion.

The morphology of the eroded surfaces, as shown in Figures 9-12, was very similar for all of the test specimens. However, it was only at the elevated test temperatures that the striation marks on the surfaces of the shallow craters could be observed. These striations are evidence of the ductility of the eroding surface. Their occurrence can be related back to the erosion rates which occurred at 500°C and 750°C compared to the rates which occurred in the 20°C tests.

Future Paper

The correlation between the microstructures of the various coatings and their erosion behavior will be presented in a subsequent paper. Also, the combined erosion-corrosion behavior of these coatings, which was determined in the ACES burner facility at the

Sandia Livermore Combustion Research Center will be presented in the next paper on this subject.

CONCLUSIONS

1. The coatings tested had different erosion resistance rankings as a function of test temperature and impingement angle with no single coating being superior at all conditions.
2. The erosion resistance of the coatings did not directly relate to their hardness.
3. The presence of hard and soft phases in the coatings' microstructures negated the established relationship between the erosion of ductile and brittle materials as a function of impingement angle.
4. Steady state erosion rates occurred for all of the materials tested after 50-150g of erodent particles had impacted their surfaces.
5. A decrease in the steady state erosion rate occurred when the test temperature was increased from 20° to 500°C.

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TABLE 1

<u>Coating</u>	<u>Supplier</u>	<u>Coating Composition/Treatment</u>	<u>Substrate</u>	<u>Coating Thickness mm</u>
Aluminized 304SS	Turbine Components Corporation	Aluminized	304SS	0.13
Aluminized 304SS	Alon Processing, Inc.	Aluminized	304SS	0.06
Chromized 1060	Combustion Engineering Inc.	Chromized	1060 steel	0.05
Carburized 1005	Combustion Engineering Inc.	Carburized	1005 steel	0.49
Metco 15E	Metco	NiCrFeSiBC	304SS	0.90
Metco 444	Metco	NiCrAlMoFe	304SS	0.98
Metco 465	Metco	FeCrAlMo	304SS	0.58

TABLE 2

<u>Coating</u>	<u>Composition %</u>								<u>Density (g/cc)</u>	<u>Hardness</u>
	Ni	Fe	Cr	Al	Mo	Si	B	C		
Metco 15E	70.5	4.0	17.0	-	-	4.0	3.5	1.0	8.0	R _c 58 (655 VHN)
Metco 444	72.5	5.0	9.0	7.0	5.5	-	-	-	7.0	R _b 74 (138 VHN)
Metco 465	-	64.5	27.5	6.0	2.0	-	-	-	6.4	R _c 25 (270 VHN)

FIGURES

1. Elevated temperature erosion tester.
2. Room temperature erosion rates at $\alpha=30^\circ$ and 90° .
3. Room temperature incremental erosion rates for surface diffused coatings at $\alpha=90^\circ$.
4. Room temperature incremental erosion rates for sprayed Metco coatings at $\alpha=90^\circ$.
5. 500°C erosion rates at $\alpha=30^\circ$ and 90° .
6. 750°C erosion rates at $\alpha=30^\circ$ and 90° .
7. Steady state erosion rates v.s. temperature for diffused coatings at $\alpha=30^\circ$.
8. Steady state erosion rates v.s. temperature for diffused coatings at $\alpha=90^\circ$.
9. Eroded surfaces of chromized 1060 steel at $\alpha=30^\circ$.
10. Eroded surfaces of chromized 1060 steel at $\alpha=90^\circ$.
11. Eroded surfaces of Metco 15E coating at $\alpha=30^\circ$.
12. Eroded surfaces of Metco 15E coating at $\alpha=90^\circ$.
13. Cross sections of Alon aluminized 304SS.
14. Cross sections of Metco 444 coating.
15. Cross section of eroded Metco 15E eroded coating.

ELEVATED TEMPERATURE EROSION - CORROSION TESTER

XBL 821-7741A

1. Elevated temperature erosion tester.

2. Room temperature erosion rates at $\alpha = 30^{\circ}$ and 90° .

XBL 848-8565

3. Room temperature incremental erosion rates for surface diffused coatings at $\alpha=90^{\circ}$.

XBL 848-8563

4. Room temperature incremental erosion rates for sprayed Metco coatings at $\alpha=90^{\circ}$.

XBL 848-8564

6. 750°C erosion rates at $\alpha=30^{\circ}$ and 90° .

XBL 848-8567

7. Steady state erosion rates v.s. temperature for diffused coatings at $\alpha=30^\circ$.

XBL 848-8561

XBL 848-8568

8. Steady State erosion rates v.s. temperature for diffused coatings at $\alpha=90^\circ$.

Chromized 1060
Steady State Erosion
 $\alpha = 30^\circ$
37 m/s
2.0 μ m SiC

20°C

500°C

750°C

20 μ m

XBB 847-5067

9. Eroded surfaces of chromized 1060 steel
at $\alpha=30^\circ$.

Chromized 1060
Steady State Erosion
 $\alpha = 90^\circ$
30 m/s
240 μ m SiC

20°C

500°C

750°C

20 μ m

XBB 847-5065

10. Eroded surfaces of chromized 1060 steel
at $\alpha=90^\circ$.

Metco 15E
Steady State Erosion
 $\alpha = 30^\circ$
30 m/s
240 μ m SiC

20°C

500°C

750°C

20 μ m

XBB 847-5068

11. Eroded surfaces of Metco 15E coating
at $\alpha=30^\circ$.

Metco 15E
Steady State Erosion
 $\alpha = 90^\circ$
30 m/s
240 μ m SiC

20°C

500°C

750°C

20 μ m

XBB 847-5066

12. Eroded surfaces of Metco 15E coating
at $\alpha=90^\circ$.

Original Surface

100μm

Original Surface

20μm

Eroded Surface

20μm

ALON ALUMINIZED 304 SS

Temp. = 20°C
Vel. = 30m/s
 α = 90°

240μm SiC
Gas : Air

XBB 8410-7956

13. Cross sections of Alon aluminized 304SS.

Original Surface

100μm

Eroded Surface

100μm

XBB 8410-7954

METCO 444

Temp. = 20°C	240μm SiC
Vel. = 30m/s	Gas : Air
α = 90°	

14. Cross sections of Metco 444 coating.

15. Cross section of eroded Metco 15E
eroded coating.

—
2 μ m

XBB 848-6117

Metco 15E

$\alpha=90^\circ$

Temp. $\approx 20^\circ\text{C}$

Vel. $\approx 30\text{m/s}$

240 μm SiC

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